What Is FM?

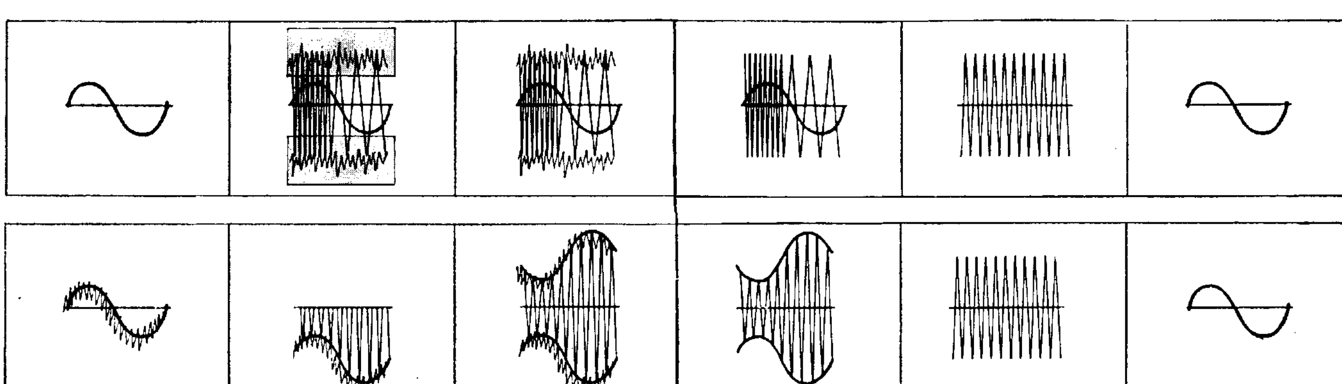
By EVERETT EDDEY, E.E. IV

Numerous advertisements have appeared recently extolling the wonders of FM, frequency modulation, for radio broadcasting. These advertisements state that FM is an entirely new and different method of radio broadcasting producing almost perfect reproduction of sound at the receiver without any static or other noise. After reading these advertisements, those people who are unfamiliar with FM may be inclined to wonder what the new principle by which FM works might be, whether or not FM actually does do away with static, and whether or not there might be some compensating disadvantages connected with FM. This article will attempt to answer these questions by presenting a discussion of the nature of sound and the manner by which it is carried from the broadcasting studio to the loudspeaker in the home receiver by FM and by the present method of radio transmission, amplitude modulation or AM. The relative merits of FM will then be considered.

As most engineers know, sound is transmitted as a wave of rarefactions and condensations of the particles in the medium transmitting the sound. In a pure tone, these rarefactions and condensations occur at constant and regular intervals. Thus when one hears the note middle C in the musical scale, the rarefactions and condensations reach the ear at the rate of 256 times a second. The sound wave for such a pure tone might be represented on paper in the manner shown in figure 1 (a) where the displacement of the particles transmitting the wave is plotted against distance through the medium. The wave moves through space in a manner similar to the motion of a water wave in a body of water. This sound wave represented in figure 1 (a) is characterized by two quantities: amplitude of vibration and frequency. The amplitude of vibration is the maximum displacement from the undisturbed position and determines the loudness of the sound. The frequency of the sound wave is the number of condensations or rarefactions occuring per second. For middle C, the frequency is 256 vibrations per second. One complete vibration, that is one condensation and one rarefaction, is shown in figure 1 (a). The pitch of a tone is determined by the frequency of its sound wave.

The complicated sounds of speech and music are composed of a sum of different pure tones of different amplitude and frequency. The normal human ear can hear sound ranging from about 16 to 16,000 vibrations per second. Frequencies in this range are referred to as audio frequencies.

It is a physical fact that electrical alternating currents and voltages are waves of a similar nature to sound waves. By means of a microphone it is possible to convert a sound wave into an equivalent electrical wave. When this electrical wave is fed into a loudspeaker, the loudspeaker functions to convert the electrical wave back into the original sound wave. The simplest type of telephone circuit consists merely of a microphone for converting sound waves into electrical waves



—*Courtesy General Electric.*

(a) Sound wave (b) Carrier (c) Modulation (d) Effect of noise (e) Action of receiver (f) Sound at loudspeaker

Figure 1. A comparison of AM and FM methods, AM above and FM below.

and of a receiver for converting the electrical waves back into sound waves.

When the problem of transmission through the air by radio is considered, it might be thought that it would be possible to send the audio frequency electrical waves out at the transmitter, have them picked up by the receiving set, and converted into sound waves in a manner similar to the action of the simple telephone circuit described above. Although this method would be theoretically possible, it is found practically that the radiation of audo frequency electrical equipment waves through space is very inefficient and would require cumbersome equipment. In addition such a method would allow only one program to broadcast at a given time.

Although audio frequency electrical waves can not be radiated efficiently or conveniety, high frequency electric waves can be. The method of radio transmission is then to superimpose an audio frequency wave upon a high frequency electric wave; or as is said, the rf wave (radio frequency, a high frequency wave) is modulated by the af (audio frequency) wave. It is in the method of modulation (superposition) that FM differs from AM.

The rf wave referred to above is known as the carrier wave and the corresponding frequency is known as the carrier frequency. The carrier wave is shown in figure 1 (b) and is the same in shape for both FM and AM. For AM, carrier frequencies vary from 550,000 vibrations (or cycles) per second to 1,600,000 cycles per second, or as is usually said, 550 kilocycles per second ("kilo" means 1,000) to 1600 kilocycles per second. "Kilocycles per second" is usually abbreviated as "kc". When one sets his radio dial at 700, he is tuning to a carrier frequency of 700 kc. Carrier frequencies in FM are much higher than with AM.

Probably the most obvious manner in which to modulate an rf wave with an af wave would be to vary the amplitude of vibration of the rf wave in accordance with the varying ampltude of the af wave. This is the actual method used in AM and is illustrated in the upper half of figure 1 (c). It will be seen that the outline or envelope of the rf wave is now the af wave. The receiver is provided with circuits for extracting the envelope from the rf wave thus obtaining the original af wave. By relatively simple mathematical analysis it can be shown that when an rf wave is modulated by an af wave of a given frequency, the resulting rf wave contains two frequency components, one of which is greater that the rf carrier wave by the amount of the af frequency and the other is smaller that the carrier frequency by the same amount. Thus when one tunes to 700 kc, the

—Courtesy General Electric.

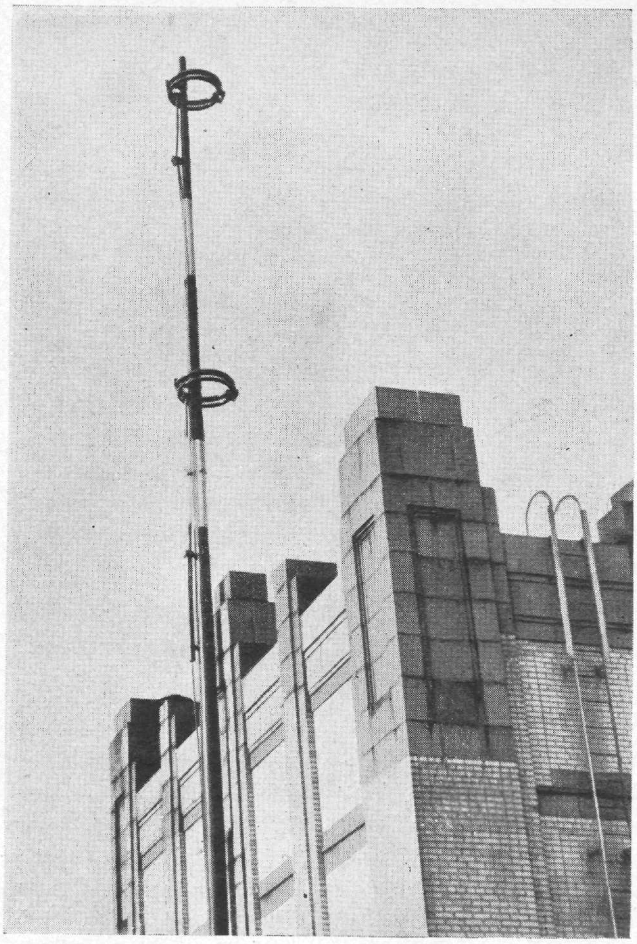
Figure 2. At the New York World's Fair, not a crackle of static came from this FM radio receiver even though powerful bolts of man-made lightning were released just a few feet away.

actual signal received varies slightly about 700 kc. By law this variation is limited to 5 kc either side of the carrier frequency, thus giving a frequency band of 10kc. Since the AM carrier frequency band extends from 550kc to 1600 kc (in this country), (1600—550)/10 or 105 "channels" are available for stations in the United States.

With FM, the frequency, instead of the amplitude, of carrier is varied according to the af signal. The effect is illustrated in the lower half of figure 1 (c). It will be observed that the amplitude of vibration of the carrier wave remains unchanged in modulation. The instantaneous frequency of the carrier wave varies according to the af signal. The interval of time required for a cycle is changed so that the carrier wave cycles become bunched together in some places and stretched out in others so that the wave shape looks somewhat like an accordion which is being played. The receiver is equipped with a circuit whose response varies as the cycles of the carrier wave are bunched together or spread out. Hence this circuit is capable of transforming the constant-amplitude, variable-frequency carrier wave into the original af wave.

Theoretically both AM and FM should produce equally good results. However the two methods differ in the amount of discrimination which they will permit between desired and undesired signals. The undesired signal may come from a radio station other than the one which the listener desires to hear or may arise from static either from natural lightning or from electrical machinery, automobile ignition systems, etc. The sources of static act just as if they were broadcasting stations transmitting irregular sounds. Therefore the interferance they produce is electrically the same as that produced by an undesired radio signal, and in this article both types of interference will be covered under the term "undesired signal".

In AM the amplitude of vibration of the undesired signal merely adds directly to the amplitude of vibration of the desired wave. This action is shown in the top half of figure 1 (d) in which the irregular variations are produced by the undesired signal. The ratio of desired signal to undesired signal in the final output of the receiver is the same as ratio of the amplitude of the desired signal to the amplitude of the undesired signal. If the amplitude of the undesired signal is 30 per cent of the amplitude of the desired signal, then the undesired signal will be 30 per cent of the desired signal in the final output of the receiver loudspeaker. This fact illustrates the greatest disadvantage of AM, namely even relative small undesirable signal will be noticable in the receiver output. It is found that an undesired signal can be detected in the output of the receiver whenever it is more than 1 per cent of the desired signal. This fact means that the desired signal must be 100 times as great as the undesired signal to give noise-free reception. The enormous amount of power that would be required for this condition to hold at reasonable distances from the radio station prohibits this method of eliminating interferance.



—*Courtesy General Electric.*

Figure 3. Two-bay circular antenna of an FM radio station.

With FM the undesired signal also adds to the desired signal as shown in the lower half of figure 1 (d). However in this case it is only variations in the frequency of the undesired signal that can affect the final output since all amplitude variations are eliminated in a "limiter" circuit in the receiver which cuts off the maximum amplitude variations as shown by the shaped portions of the lower half of figure 1 (e). Moreover, the frequency variations of the undesired signal cannot add directly to the frequency variations of the desired signal so that the effect in the final output of the undesired signal is not proportional to the magnitude of the undesired signal in comparison with the desired signal as is the case with AM. *With FM, if the desired signal is at least twice the undesired signal, the desired signal will take control, over-riding the undesired signal which is reduced to a negligible value.* This fact is the reason why FM is able to give noise-free reception. The desired signal must be merely twice the undesired signal. Of course, the reverse is also true; that is, when the undesired signal becomes greater than twice the desired signal the undesired signal takes over and the desired is blotted out. If an automobile is equipped with an FM receiver, and the car is driven away from the FM station, the reception is at first noise free. The signal strength, of course, drops as the distance from the station is increased. When the desired signal strength drops to less than twice the undesired signal strength, noise is introduced and the desired signal is soon completely blotted out. The point at which this action occurs is known as the threshold point and is a limiting factor in the range of the FM transmitter.

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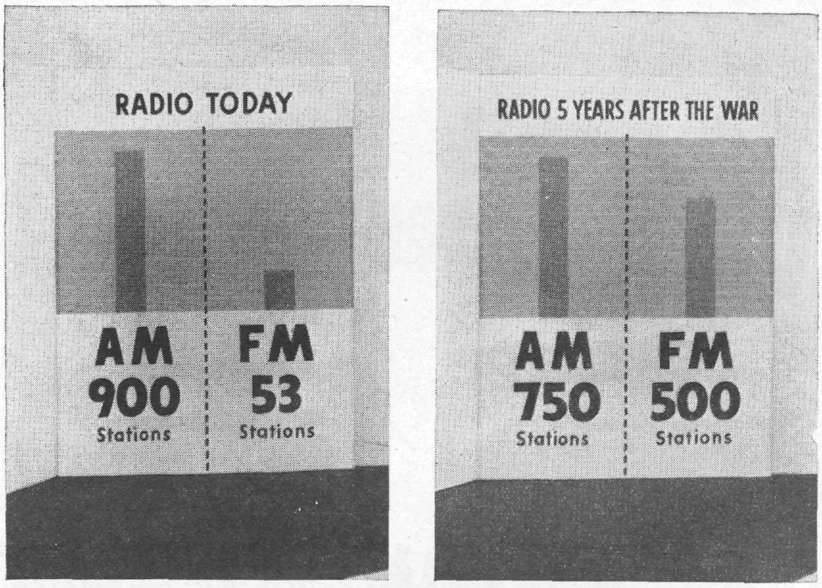
It was previously stated that there are 105 AM channels available in this country. However, there are at present about 900 AM stations in operation in this country. It will be seen that several AM stations must be assigned to the same channel. Even if these stations are separated by many miles, there will still be some interference. With FM, however, there is no interference when the signal strength of one station is twice the other. Hence two stations in different cities can be assigned the same carrier frequency without interference.

It was stated that the normal human ear can hear sounds whose frequencies range from about 16 to 16,000 cycles per second. However, AM stations are permitted to transmit only signals representing sounds up to 5,000 cycles per second. With FM sounds of frequencies up to 15,000 cycles can be transmitted. These high frequency sounds represent harmonics and overtones which give quality to the sounds being received. Hence the quality of reception with FM is inherently better than with AM.



—Courtesy General Electric.

Figure 4. A predicted development of AM and FM.

The advantages of FM over AM are then noise-free reception of better quality. Now, what are the disadvantages of FM? The reader will reall that with AM the frequency of a radio signal varies about 5kc on either side of the carrier frequency. With FM the frequency must vary about 100 kc on either side of the carrier frequency. Now, it is desirable that this frequency swing be but a small percentage of the carrier frequency. In order for this condition to hold with FM, it has been necessary to use very high frequency carrier frequencies. The Federal Communications Commission now proposes to use carrier frequencies of about 100,000 kc for FM stations. These high frequencies present the chief difficulties connected with FM. At first convenient or suitable equipment was not available to handle these frequencies. However, recently great advances have been made in the development of high frequency equipment so that probably the lack of proper equipment can no longer be considered a disadvantage of FM.

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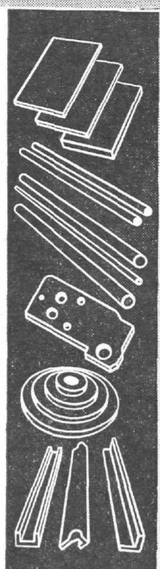
Leeuwenhoek Saw a New World in a Tiny Bead of Glass



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FABRICATED PARTS

MOLDED MACERATED and MOLDED LAMINATED FORMS and PRODUCTS

HISTORY does not reveal who invented the microscope. But it was a Dutch merchant, Anthony Van Leeuwenhoek who made it practical. Peering through a tiny bead of glass he ground into a lens, he became the first to see the organisms of the microscopic world.

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However, it should be noted that new equipment will be needed both for the transmission and reception of FM broadcast. This fact means that there must be considerable money laid out for the purchase of new equipment and represents a certain economic disadvantage.

There are, however, certain more basic disadvantages connected with the use of high frequencies. As the frequency of a radio wave is increased, its properties become more nearly like those of light waves. Thus at the frequency used in FM the waves travel in straight lines as light waves do. Hence the range of an FM transmitter is limited to the optical horizon (or the the threshold distance if this distance is smaller) The practical effect of these statements is to limit the range of an FM transmitter to about 75 miles. This range would be satisfactory in metropolitan regions, but would not give very good coverage for country districts.

In addition to this limitation of range, high frequency radio waves have the additional disadvantage that buildings and hills cast shadows into the waves just as they produce shadows in sunlight. This fact means that reception is difficult behind a building or hill. This disadvantage can be remedied to some extent by good receiving antenna design, but there still remain some regions in which reception is impossible. Fortunately, these regions are small in comparison with the regions in which reception is possible, but the people in these regions are just out of luck.

Among other disadvantages is the fact that few radio repairmen, at present, know how to service FM receivers so that the owner of an FM receiver may experience considerable difficulty in obtaining repairs on his receiver. Presumably this disadvantage will no longer exist when FM becomes more common. In addition, special and new equipment is needed in the telephon circui s supplying the FM networks thus providing additional equipment costs. Still another disadvantage is the fact that automobile ignition systems and some other sources of static seem to have more effect on FM reception than AM reception.

Well, just what does the future hold for FM and AM? Apparently, most people in the radio industry feel the advantage of FM greatly outweighs its disadvantages for great expansion in this field has been planned for the post-war period. However, the reader should not assume that AM is going to be entirely replaced. AM has certain invaluable advantages over FM. Its wider range is useful in communications work (for

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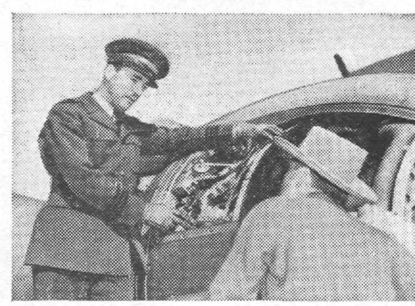
2. The Westerner operates a ranch that was literally made possible by power — electricity and irrigation from the great Boulder Dam harnessing the Colorado River. Power which made possible the conversion of millions of acres of barren wilderness into fertile ranches and farms!



3. No wonder he's eager to hear the pilot tell of a new super-power — such as that of the Wright Cyclone . . . the engine which speeds the great Boeing B-29 Superfortress across the air miles to Tokyo . . . power that makes possible a trans-Atlantic flight every 13 minutes.

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FM will probably replace AM for local stations where the advantages of FM can be put to greatest use. This will leave clear channels available for high power AM stations whose greatest range will provide coverage for regions not covered by FM.

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example, by the military services) where it is desired merely to transmit intelligence for a long distance and noise is not important. In the future